EARTHWORMS IN SOIL FORMATION, STRUCTURE AND FERTILITY

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ABSTRACT

The importance of earthworm activity has been recognized since ancient times and their role in pedogenesis and soil fertility has been studied since the late 1800's. Earthworms contribute to soil structure and formation through burrowing, comminution of organic matter and by formation of aggregates. Earthworm guts are important sites of microbial action whereby nutrients are made available to plants. Earthworm burrows are conspicuous aspects of soil structure and contribute to soil aeration and drainage. Earthworm populations can be extremely dense in soils with abundant organic matter, although species diversity of earthworm assemblages is relatively low. Empirical data suggest that introduction of earthworms can improve impoverished soils. However, important information about taxonomy, distribution and biology of North American species is lacking. Few ecological studies have examined relationships between earthworms and other organisms in the soil.

RÉSUMÉ

L'importance de l'activité des vers de terre est connue depuis les temps anciens, et leur rôle dans la pédogénèse et la formation des sols est le sujet d'études depuis la fin du XIXième siècle. Les vers de terre contribuent à la structure et à la formation des sols en fouissant, en pulvérisant la matière organique et en formant des agrégats. Le tube digestif des vers de terre est le site important d'une action microbienne par laquelle les nutriments sont libérés des tissus végétaux. Les galeries de vers forment un aspect frappant de la structure du sol et contribuent à son aération et à son drainage. Les populations de vers peuvent être extrêmement denses dans les sols riches en matières organiques, mais la diversité des espèces en est relativement faible. Des données empiriques suggèrent que l'introduction de vers de terre peut améliorer les sols appauvris. On manque cependant d'informations essentielles sur la taxonomie, la répartition géographique et l'histoire naturelle des espèces de vers nord-américaines. Peu d'études écologiques ont examinées les rapports entre les vers de terre et les autres organismes du sol.

INTRODUCTION

The great importance of the soil biota in soil pedogenesis and in the maintenance of structure and fertility is not always fully appreciated by soil scientists. Earthworms are probably one of the most important components of the soil biota in terms of soil formation. Although they are not numerically dominant, their large size makes them one of the major contributors to animal biomass, and their activities are such that they are extremely important in maintaining soil fertility in a variety of ways.

Aristotle was the first to draw attention to their role in turning over the soil and he aptly called them "the intestines of the earth". However, it was not until the late 1800's that Charles Darwin, in his definitive work, "The Formation of Vegetable Mould Through the Action of Worms", defined the extreme importance of earthworms in breakdown of dead plant and animal matter that reaches soil and in the continued maintenance of soil structure, aeration drainage and fertility. His views were supported and expanded subsequently by other contemporary scientists such as Muller (1878) and Urquhart (1887) and many others.

Earthworms belong to the Order Oligochaeta which contains about 3,000 species, although considerable numbers of these are aquatic in habit, and there is considerable controversy on their systematics. They are found in most parts of the world, except those with extreme climates, such as deserts and areas under constant snow and ice. Some species of earthworms, particularly those belonging to the Lumbricidae, are extremely widely distributed ('peregrine') and often, these species when introduced to new areas, become dominant over the endemic species; this situation probably applies to parts of the northern United States and Canada, particularly those close to major waterways. However, the endemic earthworm fauna of North America has not been well studied. Endemic species include those in the Acanthodrilidae with its most abundant genus *Diplocardia*, members of the Sparganophilidae and species in the Megascolecidae of which the most common genus is *Pheretima*.

EARTHWORMS AND SOIL

Soil Formation

Earthworms are extremely important in soil formation, principally through their activities in consuming organic matter, fragmenting it and mixing it intimately with mineral particles to form *aggregates*. During their feeding, earthworms greatly promote microbial activity which in turn also accelerates the breakdown of organic matter. Different species of worms do not all affect soil formation in the same way. Some species consume mainly inorganic fractions of soil, whereas others feed almost exclusively on decaying organic matter. They can deposit their feces as casts either on the soil surface or leave them in their burrows, depending on the species concerned, but all species contribute in different degrees to the comminution and mixing of the organic and inorganic components of soil, and decrease the size of not only organic but also mineral particles (Joshi and Kelkan, 1952; Shrikhande and Pathak, 1951). During passage through the earthworm gut, the different kinds of particles become mixed intimately and form aggregates, which improve both the drainage and moisture-loading capacity of the soil. These aggregates are usually very stable and improve many of the desirable characteristics of soils. There have been various suggestions as to the possible ways in which earthworms form aggregates, such as by production of gums (Swaby, 1950), or calcium humate (Meyer, 1943), by plant residues (Ponomareva, 1953) or by means of polysaccharide molecules (Parle, 1963). Various authors have estimated that up to 50% of the aggregates in the surface layers of soil are formed by earthworms (Kubiena, 1953).

Earthworms move large amounts of soil from the deeper strata up to the surface. The amounts moved in this way range from 2 - 250 tons per ha per annum, equivalent to bringing a layer of soil between 1 mm and 5 cm thick to the surface every year, creating a stone-free layer on the soil surface. Earthworms also affect soil structure in other ways. Some species make 'permanent' burrows, whereas others move randomly through soil leaving cracks and crevices of different sizes. Both sorts of burrows are important in maintaining both *soil aeration* and *drainage*. Moreover, earthworm burrows are usually lined with a protein-based mucus, which helps to stabilize these cavities, and many of the species with permanent burrows cast their feces aroung the lining of their burrows, the cast material usually containing more plant nutrients in a readily available form than the surrounding soil. There is good evidence that earthworm activity increases the *porosity* and *air to soil volume* (Wollny, 1890; Hopp, 1974; Edwards and Lofty, 1977). Burrows are also important in improving *soil drainage*, particularly since those of some species, such as *Lumbricus terrestris* L. penetrate deep into soil (Edwards and Lofty, 1978, 1982) and can even pass through layers of clay. The burrows and pores also increase the *infiltration rate* greatly (Slater and Hopp, 1947; Teotia *et al.*, 1950; Carter *et al.*, 1982), and there are numerous reports of water penetrating the surface soil between two and ten times faster when earthworms were present than when they were not (Stockdill, 1966; Wilkinson, 1975; Tisdall, 1978). This effect on infiltration can be of two kinds; firstly, the presence of large surface-opening holes which are not usually taken into account by soil scientists when conventional models of infiltration are developed (Edwards *et al.*, 1979), and secondly, the crevices also created by earthworms, but which are much smaller, not only increase infiltration but also aid in water retention.

Finally, earthworm activity makes a significant contribution to soil *aeration* (Stockli, 1928; Kretzschmar, 1978), by creating channels, particularly in heavy soils which allow air to penetrate into the deeper layers of soil, minimizing the incidence of anaerobic layers.

Organic matter breakdown and incorporation into soil

Although all species of earthworms contribute to the breakdown of plant-derived organic matter, they differ in the ways in which they breakdown organic matter. Their activities can be of three kinds, each associated with a different group of species. Some species are limited mainly to the plant litter layer on the soil surface, decaying organic matter or wood, and seldom penetrate soil more than superficially. The main role of these species seems to be comminution of the organic matter into fine particles which facilitates microbial activity. Other species live just below the soil surface most of the year, except when very cold or very dry, do not have permanent burrows and ingest both organic matter and inorganic materials. These species produce organically enriched soil materials in the form of casts, which they deposit either randomly in the surface layers of soil or as distinct casts on the soil surface. Finally, there are the truly soil-inhabiting species which have permanent burrows that penetrate deep into the soil. These species feed primarily on organic matter but also ingest considerable quantities of inorganic materials and mix these thoroughly through the soil profile. These latter species are of primary importance in pedogenesis. All species depend on consuming organic matter in some form and play an important role in the final stage of organic matter decomposition, which is humification into complex amorphous colloids containing phenolic meterials, probably by promoting microbial activity.

There is little doubt that in many habitats, earthworms are the key organisms in the breakdown of plant organic matter. Populations of earthworms usually expand in relation to the availability of organic matter, and in many temperate and even tropical forests, it seems that earthworms have the capacity to consume the total annual litter fall. Such a total turnover has been calculated for an English mixed woodland (Satchell, 1967), an English apple orchard (Raw, 1962), a tropical forest in Nigeria (Madge, 1965), an oak forest in Japan (Sugi and Tanaka, 1978) and it seems likely that similar calculations would be valid for other sites (Edwards and Lofty, 1977).

During feeding by earthworms, the carbon:nitrogen ratio in the organic matter falls progressively and, moreover, the nitrogen is converted into the ammonium or nitrate form. At the same time the other nutrients, P and K, are converted into a form available to plants. Soils that have poor populations of earthworms often develop a mor structure with a mat of undecomposed organic matter at the soil surface (Kubiena, 1953); this can also occur in grassland and is common on poor upland grasslands in temperate countries and in New

Zealand in areas where earthworms have not yet been introduced (Stockdill, 1966).

ECOLOGICAL ASPECTS OF EARTHWORMS

Abundance and Diversity

Populations of earthworms vary greatly both in terms of numbers or biomass and diversity. Populations range from only a few per square meter to more than 1,000 per square meter. Numbers depend on a wide range of factors, including soil type, pH, moisture-loading capacity of the soil, rainfall and ambient temperatures, but, most importantly, to the availability of organic matter. Populations in cultivated land seldom exceed 100 per square meter, or 400 per square meter in grassland, the larger populations usually being found in woodlands where the availability of organic matter is seldom limiting, and occasionally numbers as high as 2,000 per square meter have been recorded, although few earthworms occur in the more acid soils under coniferous forests. Usually, the largest populations are of lumbricid earthworms which seem to be able to survive adverse conditions much better than species belonging to the other families.

The diversity of species of earthworms varies greatly and there tend to be species associations in different soil types and habitats. The associations of species of lumbricids in temperate countries tend to be less diverse than those from other families in warmer latitudes. However, even in the most complex system, the diversity of species does not seem to be very great, rarely exceeds 10 and commonly, there are only 3-5 species. There is some evidence that species that fill the same eological niche do not normally occur in the same degree of abundance at a particular site (Edwards and Lofty, 1982).

Needs for earthworm research

In view of the great importance of earthworms in soil formation and maintenance of soil fertility, although the numbers of publications on earthworm biology and ecology is increasing rapidly, there still seems an urgent need for greatly expanded research, particularly on some aspects of earthworm activity.

We still have inadequate knowledge of the basic biology and ecology of even the more common species of lumbricids. Very few studies have addressed the problems of the detailed interrelationships between earthworms, micro-organisms and decaying organic matter and its incorporation into soil. There is good empirical evidence that introduction of earthworms together with organic matter, into impoverished soil with addition of organic matter and adjustment of pH, can increse their fertility greatly, but we have little knowledge of the mechanism of such increases or even the best ways of introducing earthworms.

Most important is the world-wide lack of knowledge of the distribution of earthworms and populations of the different species. Until we know more of the fundamental biology and ecology and the activities of the many different species and their role in maintaining soil structure and fertility, it is impossible to assess their potential role in soil improvement. These problems are particularly acute in North America where earthworm specialists are rare and research extremely sparse.

REFERENCES

Carter, A., J. Heinonen and J. deVries. 1982. Earthworms and water movement. *Pedobiologia 23*, 395–397.

Darwin, C.R. 1881. "The formation of Vegetable Mould through the Action of Worms, with

Observations on Their Habits". Murray, London. 326 pp.
Edwards, C.A. and J.R. Lofty. 1977. "Biology of Earthworms". 2nd Edition, 333 pp.
Edwards, C.A. and J.R. Lofty. 1978. The influence of arthropods and earthworms upon root growth of direct drilled cereals. *Journal of Applied Ecology 15*, 789–795.
Edwards, C.A. and J.R. Lofty. 1982. The effect of direct drilling and minimal cultivation on earthworm populations. *Journal of Applied Ecology, 19*, 723–734.
Edwards, W.M., R.R. Van der Ploeg and W. Ehlers. 1979. A numerical study of noncapillary sized pores upon infiltration. *Journal of the Soil Science Society of America 43*, 851–856.
Hopp, H. 1974. What every gardener should know about earthworms. Garden Way Publishing Company, Charlotte VT, U.S.A. 39 pp.
Joshi, N.V. and B.V. Kelkar. 1952. The role of earthworms in soil fertility. *Indian Journal of Agricultural Science 22*, 189–196.
Kretzschmar, A. 1978. Quantification écologique des gaeeries de lombriciens. Techniques et premieres estimations. *Pedobiologia 18*, 31–38.
Kubiena, W.L. 1953. "The Soils of Europe". Murray, London. 317 pp.
Madge, D.S. 1965. Leaf fall and disappearance in a tropical forest. *Pedobiologia 5*, 273–288.
Meyer, L. 1943. Experimenteller Beitrage zu makrobiologischen Wirkungen auf Humus and Boden bildung. *Archives Pflanzenernahrung Dungung Bodenkunde 29*, 119–140.
Muller, P.E. 1878. Studier over Skovjord I. Om Bogemuld od Bogemor paa Sand og Ler. *Tidsskrift Skogbruk 3*, 1–124.
Parle, J.N. 1963. A microbiological study of earthworm casts. *Journal of General Microbiology 31*: 1–13.
Ponomareva, S.I. 1953. The influence of the ctivity of earthworms on the creation of a stable structure in a sod-podzolised soil. *Trudy Pochvenie Institut Dokuehaeve 41*: 304–318.
Raw, F. 1962. Studies of earthworm populations in orchards. I. Leaf burial in apple orchards. *Annals of Applied Biology 50*, 389–404.
Satchell, J.E. 1967. pp. 259–322. *In*: Burgess, A. and F. Raw (Editors). "Soil biology". Academic Press, London.
Scrickhande, J.E. and A.N. Pathak. 1951. A comparative study of the physico-chemical characters of the castings of different insects. *Indian Journal of Agricultural Science 21*, 401–407.
Slater, C.S. and H. Hopp. 1947. Relation of fall protection to earthworm populations and soil physical conditions. *Proceedings of the Soil Science Society of America 12*, 508–511.
Stockdill, S.M.J. 1966. The effect of earthworms on pastures. *Proceedings of the New Zealand Ecological Society 13*, 68–75.
Stockli, A. 1928. Studien uber den Einfluss der Regenwurmer auf die Beschaffenheit des Bodens. *Landwirtschaft Jahrbuch Schweiz*. 42, 1.
Sugi, Y. and M. Tanaka. 1978. Number and biomass of earthworm populations, pp. 171–178. *In*: Kira, T., Y. Ono and T. Hosokawa (Editors). "Biological production in a warm temperature evergreen oak forest of Japan". J.I.B.P. Synthesis *18* University of Tokyo Press.
Swaby, R.J. 1950. The influence of earthworms on soil aggregation. *Journal of Soil Science 1*, 195–197.
Teotia, S.P., F.L. Duley and T.M. McCalla. 1950. Effect of stubble mulching on number and activity of earthworms. Nebraska Agricultural Experiment Station Bulletin *165*, 20.
Tisdall, J.M. 1978. Ecology of earthworms in irrigated orchards. pp. 297–303. *In*: Emerson, W.W., R.D. Bond and A.R. Dexter (Editors). "Modification of Soil Structure". Wiley,

Chichester.
Urquhart, A.T. 1887. On the work of earthworms in New Zealand. *Transactions of the New Zealand Institute 19*, 119–123.
Wollny, E. 1890. Untersuchungen über die Beeinflussung der Fruchtbarkeit der Ackerkrume durch die Tätigdeit der Regenwürmer. *Forschungen Gebeit Agrik Physik Bodenkunde 13*, 381–395.
Wilkinson, G.E. 1975. Effect of grass fallow rotations on the infiltration of water into a savanna zone soil of Northern Nigeria. *Tropical Agriculture (Trinidad) 52*, 97–103.